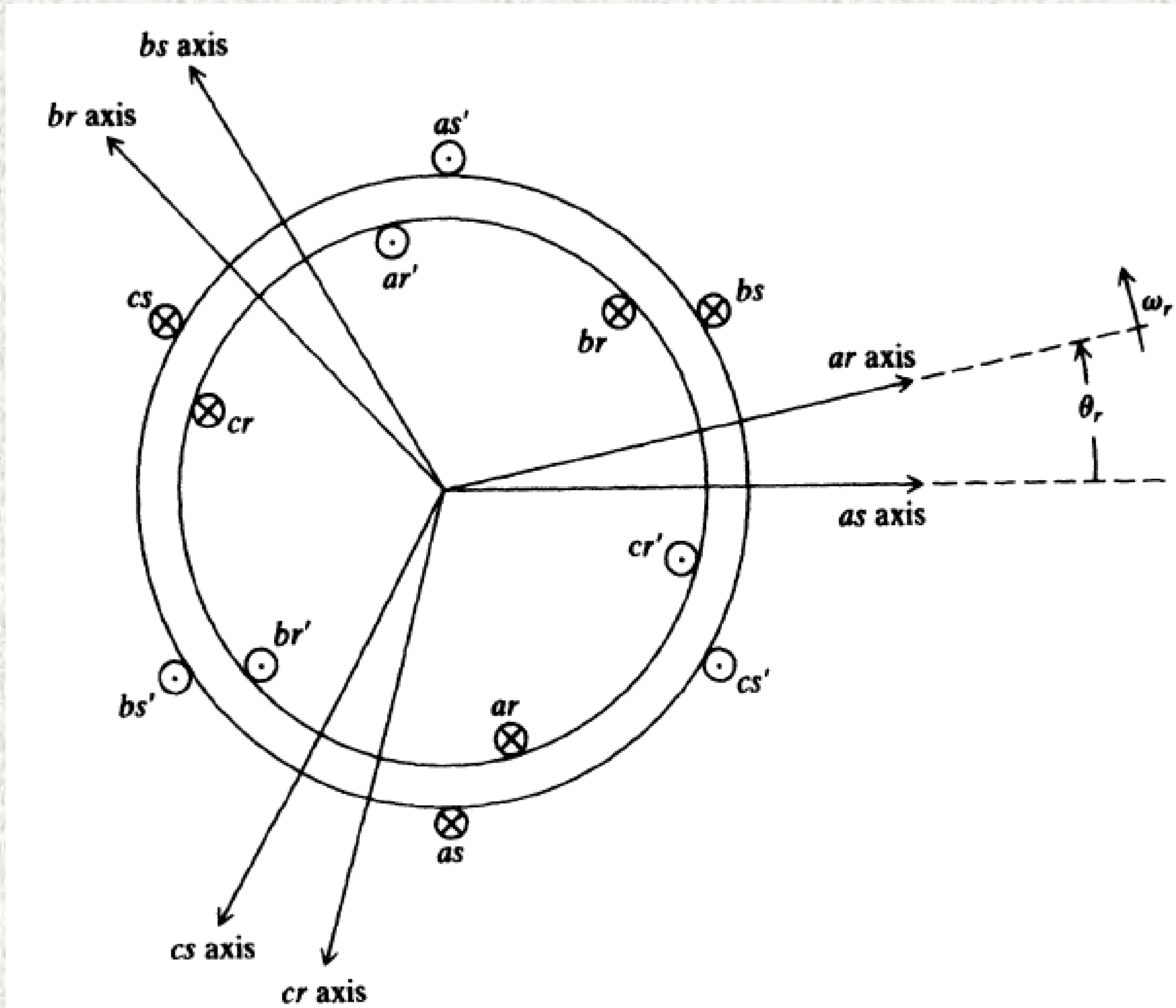
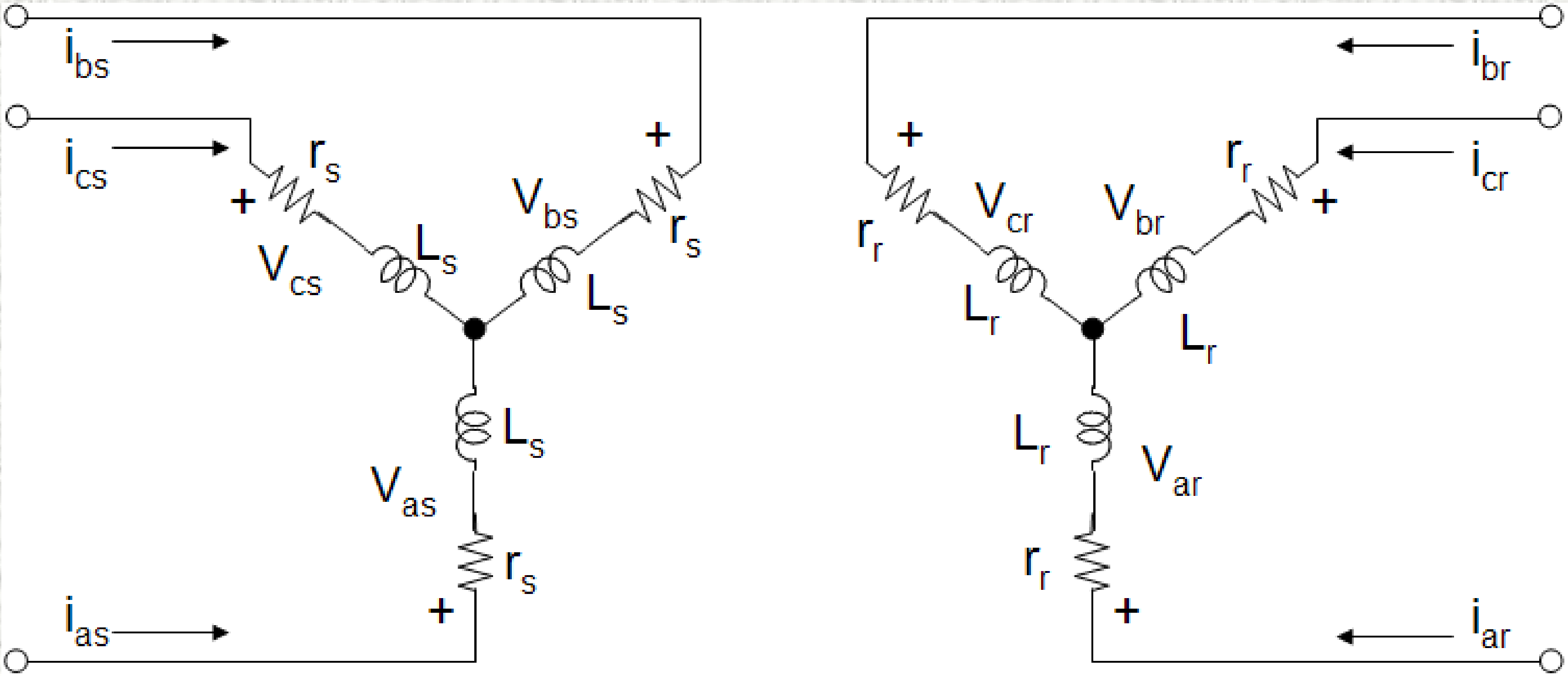
3-Phase Induction Machines



A 2-pole, 3-phase symmetrical induction machine.

3-Phase Induction Machines



A 2-pole, 3-phase symmetrical induction machine.

3-Phase Induction Machines

- In abc reference frame, voltage equations can be written as

$$V_{abcs} = r_s i_{abcs} + p\lambda_{abcs}$$

$$V_{abcr} = r_r i_{abcr} + p\lambda_{abcr}$$

$$(f_{abcs})^T = \begin{bmatrix} f_{as} & f_{bs} & f_{cs} \end{bmatrix}, \quad (f_{abcr})^T = \begin{bmatrix} f_{ar} & f_{br} & f_{cr} \end{bmatrix}$$

s: denotes variables and parameters associated with the stator circuits.

r: denotes variables and parameters associated with the rotor circuits.

3-Phase Induction Machines

$$\begin{bmatrix} \lambda_{abcs} \\ \lambda_{abcr} \end{bmatrix} = \begin{bmatrix} L_s & L_{sr} \\ (L_{sr})^T & L_r \end{bmatrix} \begin{bmatrix} i_{abcs} \\ i_{abcr} \end{bmatrix}$$

where,

$$\mathbf{L}_s = \begin{bmatrix} L_{ls}+L_{ms} & -\frac{1}{2}L_{ms} & -\frac{1}{2}L_{ms} \\ -\frac{1}{2}L_{ms} & L_{ls}+L_{ms} & -\frac{1}{2}L_{ms} \\ -\frac{1}{2}L_{ms} & -\frac{1}{2}L_{ms} & L_{ls}+L_{ms} \end{bmatrix}, \quad \mathbf{L}_r = \begin{bmatrix} L_{lr}+L_{mr} & -\frac{1}{2}L_{mr} & -\frac{1}{2}L_{mr} \\ -\frac{1}{2}L_{mr} & L_{lr}+L_{mr} & -\frac{1}{2}L_{mr} \\ -\frac{1}{2}L_{mr} & -\frac{1}{2}L_{mr} & L_{lr}+L_{mr} \end{bmatrix}$$

L_{ls} and L_{ms} are, respectively, the leakage and magnetizing inductance of the stator windings.

L_{lr} and L_{mr} are, respectively, the leakage and magnetizing inductance of the rotor windings.

3-Phase Induction Machines

$$\mathbf{L}_{sr} = \mathbf{L}_{rs} = \mathrm{L}_{rs}\begin{bmatrix} \cos\theta_r & \cos(\theta_r + \frac{2\pi}{3}) & \cos(\theta_r - \frac{2\pi}{3}) \\ \cos(\theta_r - \frac{2\pi}{3}) & \cos\theta_r & \cos(\theta_r + \frac{2\pi}{3}) \\ \cos(\theta_r + \frac{2\pi}{3}) & \cos(\theta_r - \frac{2\pi}{3}) & \cos\theta_r \end{bmatrix},$$

L_{sr} : the mutual inductances between stator and rotor windings

- squirrel-cage rotor: the current flows in copper or aluminum bars which are uniformly distributed in a common ring at each end of the rotor
- in a practical machine, the rotor conductors are skewed slightly with the axis of rotation to reduce the magnitude of harmonic torques

Referring all rotor variables to the stator windings

- Rotor variables can be referred to the stator windings by appropriate turns ratio:

$$i'_{abcr} = \frac{N_r}{N_s} i_{abcr}, \quad V'_{abcr} = \frac{N_s}{N_r} V_{abcr}, \quad \lambda'_{abcr} = \frac{N_s}{N_r} \lambda_{abcr}, \quad L_{ms} = \left(\frac{N_s}{N_r}\right)^2 L_{sr}$$

$$\left[\mathbf{L}'_{sr}\right] = \frac{N_s}{N_r}\left[\mathbf{L}_{sr}\right] = L_{ms}\begin{bmatrix} \cos\theta_r & \cos(\theta_r + \frac{2\pi}{3}) & \cos(\theta_r - \frac{2\pi}{3}) \\ \cos(\theta_r - \frac{2\pi}{3}) & \cos\theta_r & \cos(\theta_r + \frac{2\pi}{3}) \\ \cos(\theta_r + \frac{2\pi}{3}) & \cos(\theta_r - \frac{2\pi}{3}) & \cos\theta_r \end{bmatrix},$$

Referring all rotor variables to the stator windings

- Also,

$$L_{mr} = \left(\frac{N_r}{N_s}\right)^2 L_{ms}, \quad [\mathbf{L}'_r] = \left(\frac{N_r}{N_s}\right)^2 [\mathbf{L}_r]$$

$$[\mathbf{L}'_r] = \begin{bmatrix} L'_{lr} + L_{mr} & -\frac{1}{2}L_{ms} & -\frac{1}{2}L_{ms} \\ -\frac{1}{2}L_{ms} & L_{lr} + L_{ms} & -\frac{1}{2}L_{ms} \\ -\frac{1}{2}L_{ms} & -\frac{1}{2}L_{ms} & L_{lr} + L_{ms} \end{bmatrix}$$

where,

$$L'_{lr} = \left(\frac{N_s}{N_r}\right)^2 L_{lr}$$

Referring all rotor variables to the stator windings

- Flux linkage may be expressed as

$$\begin{bmatrix} \lambda_{abcs} \\ \lambda'_{abcr} \end{bmatrix} = \begin{bmatrix} \mathbf{L}_s & \mathbf{L}'_{sr} \\ (\mathbf{L}'_{sr})^T & \mathbf{L}'_r \end{bmatrix} \begin{bmatrix} i_{abcs} \\ i'_{abcr} \end{bmatrix}$$

- Voltage equations expressed in terms of machine variables referred to the stator windings may be written as

$$\begin{bmatrix} V_{abcs} \\ V'_{abcr} \end{bmatrix} = \begin{bmatrix} \mathbf{r}_s + p\mathbf{L}_s & p\mathbf{L}'_{sr} \\ p(\mathbf{L}'_{sr})^T & \mathbf{r}'_r + p\mathbf{L}'_r \end{bmatrix} \begin{bmatrix} i_{abcs} \\ i'_{abcr} \end{bmatrix}$$

where, $r'_r = \left(\dfrac{N_s}{N_r}\right)^2 r_r$

Torque Equation in Machine Variables

- Energy stored in the coupling field may be written as:

$$W_c = W_f = \frac{1}{2}(i_{abcs})^T(\mathbf{L}_s - \mathbf{L}_{ls}\mathbf{I})i_{abcs} +$$

$$(i_{abcs})^T(\mathbf{L}_{sr})i'_{abcr} + \frac{1}{2}(i'_{abcr})^T(\mathbf{L}'_r - \mathbf{L}'_{lr}\mathbf{I})i'_{abcr}$$

where, **I**: identity matrix

- Voltage equations expressed in terms of machine variables referred to the stator windings may be written as:

$$T_e(i_j, \theta_r) = \frac{P}{2}\frac{\partial W_c(i_j, \theta_r)}{\partial \theta_r}$$

Torque Equation in Machine Variables

- Since $\mathbf{L}_s$ and $\mathbf{L}_r$ are functions of θ_r, the above equation for the electromagnetic torque yields.

$$T_e = (\frac{p}{2})(i_{abcs})^T \frac{\partial}{\partial \theta_r}[\mathbf{L}'_{sr}]i'_{abcr}$$

$$= -\frac{P}{2}L_{ms}\left\{ \begin{array}{l} \left[i_{as}(i'_{ar} - \frac{1}{2}i'_{br} - \frac{1}{2}i'_{cr}) + i_{bs}(i'_{br} - \frac{1}{2}i'_{ar} - \frac{1}{2}i'_{cr}) + i_{cs}(i'_{cr} - \frac{1}{2}i'_{br} - \frac{1}{2}i'_{ar}) \right]\sin\theta_r \\ + \frac{\sqrt{3}}{2}\left[i_{as}(i'_{br} - i'_{cr}) + i_{bs}(i'_{cr} - i'_{ar}) + i_{cs}(i'_{ar} - i'_{br}) \right]\cos\theta_r \end{array} \right\}$$

- The torque and rotor speed are related by

$$T_e = J\left(\frac{2}{P}\right)p\omega_r + T_L$$

Transformation of Rotor Windings to the Arbitrary Reference Frame

- In the analysis of induction machines it is desirable to transform the variables associated with the symmetrical rotor windings to the arbitrary reference frame.

$$f'_{qd0r} = \mathbf{K}_r f'_{abcr}$$

$$(f'_{qd0r})^T = \begin{bmatrix} f'_{qr} & f'_{dr} & f'_{0r} \end{bmatrix}$$

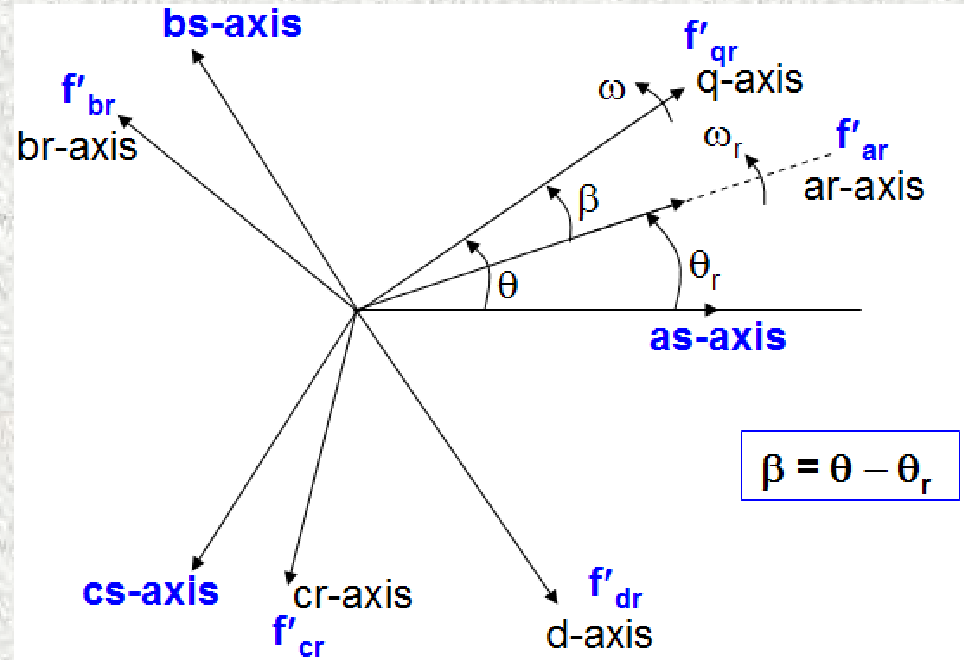
$$(f'_{abcr})^T = \begin{bmatrix} f'_{ar} & f'_{br} & f'_{cr} \end{bmatrix}$$

$$\mathbf{K}_r = \frac{2}{3}\begin{bmatrix} \cos\beta & \cos(\beta - \frac{2\pi}{3}) & \cos(\beta + \frac{2\pi}{3}) \\ \sin\beta & \sin(\beta - \frac{2\pi}{3}) & \sin(\beta + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix},$$

Transformation of Rotor Windings to the Arbitrary Reference Frame

where, $\beta=\theta-\theta_r$

$$\theta_r = \int_0^t \omega_r(t)dt + \theta_r(0)$$



$$(\mathbf{K}_r)^{-1} = \begin{bmatrix} \cos\beta & \sin\beta & 1 \\ \cos(\beta - \frac{2\pi}{3}) & \sin(\beta - \frac{2\pi}{3}) & 1 \\ \cos(\beta + \frac{2\pi}{3}) & \sin(\beta + \frac{2\pi}{3}) & 1 \end{bmatrix}$$

"r" subscript indicates the variable, parameters and transformation associated with rotating circuits.

Voltage Equations in Arbitrary Reference Frame Variables

- For two-pole, 3-phase symmetrical induction,

$$\overline{V}_{abcs} = \bar{r}_s i_{abcs} + p\lambda_{abcs}$$
$$V'_{abcr} = r'_r i'_{abcr} + p\lambda'_{abcr}$$

$$\lambda_{abcs} = \left(\overline{L}_s\right) i_{abcs} + \left(L'_{sr}\right) i'_{abcr}$$
$$\lambda'_{abcr} = \left(\overline{L}'_{sr}\right)^T i_{abcs} + \left(L'_r\right) i'_{abcr}$$

$$\overline{V}_{abcs} = \mathbf{K}_s \overline{V}_{qd0s}, \quad i_{abcs} = \mathbf{K}_s \bar{i}_{qd0s}$$
$$V'_{abcr} = \mathbf{K}_r \overline{V}'_{qd0r}, \quad i'_{abcr} = \mathbf{K}_r \bar{i}'_{qd0s}$$

Voltage Equations in Arbitrary Reference Frame Variables

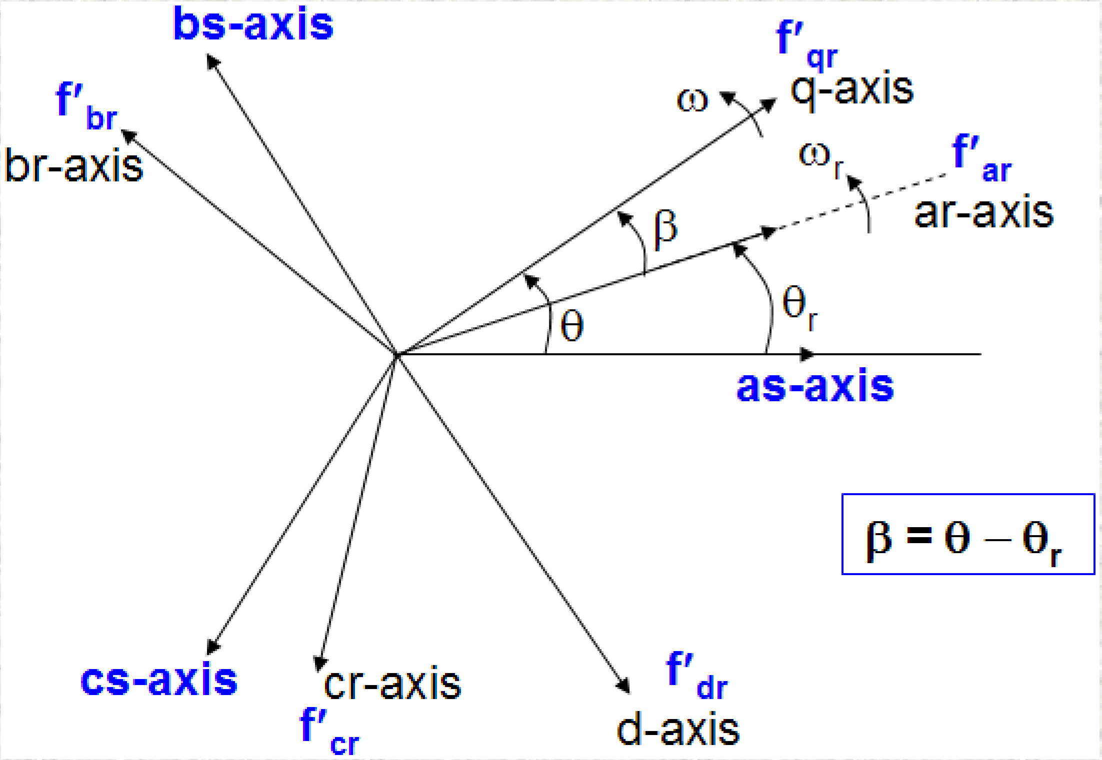


Fig.1 Axis of 2-pole, 3-phase symmetrical induction.

Voltage Equations in Arbitrary Reference Frame Variables

- Using the above transformation equations, we can transform the voltage equations to an arbitrary reference frame rotating at speed of ω.

$$V_{qd0s} = r_s i_{qd0s} + \omega\lambda_{qds} + p\lambda_{qd0s}$$

$$V'_{qd0r} = r'_r i_{qd0r} + (\omega - \omega_r)\lambda'_{qdr} + p\lambda'_{qd0r}$$

$$where, \quad (\lambda_{qds})^T = \begin{bmatrix}\lambda_{ds} & -\lambda_{qs} & 0\end{bmatrix}, \quad (\lambda'_{qdr})^T = \begin{bmatrix}\lambda'_{dr} & -\lambda'_{qr} & 0\end{bmatrix}$$

- Flux linkage equations in abc reference frame can be transformed to qd axes using K_s and K_r transformation matrices.

Voltage Equations in Arbitrary Reference Frame Variables

$$\begin{bmatrix} \lambda_{qd0s} \\ \lambda'_{qd0r} \end{bmatrix} = \begin{bmatrix} \mathbf{K}_s \mathbf{L}_s (\mathbf{K}_s)^{-1} & \mathbf{K}_s \mathbf{L}'_{sr} (\mathbf{K}_r)^{-1} \\ \mathbf{K}_r \mathbf{L}'_{sr} (\mathbf{K}_s)^{-1} & \mathbf{K}_r \mathbf{L}'_r (\mathbf{K}_r)^{-1} \end{bmatrix} \begin{bmatrix} i_{qd0s} \\ i'_{qd0r} \end{bmatrix}$$

where,

$$\mathbf{K}_s \mathbf{L}_s (\mathbf{K}_s)^{-1} = \begin{bmatrix} L_{ls} + M & 0 & 0 \\ 0 & L_{ls} + M & 0 \\ 0 & 0 & L_{ls} + M \end{bmatrix}, \quad M = \frac{3}{2} L_{ms}$$

$$\mathbf{K}_r \mathbf{L}'_r (\mathbf{K}_r)^{-1} = \begin{bmatrix} L'_{lr} + M & 0 & 0 \\ 0 & L'_{lr} + M & 0 \\ 0 & 0 & L'_{lr} + M \end{bmatrix}, \quad M = \frac{3}{2} L_{ms}$$

Voltage Equations in Arbitrary Reference Frame Variables

$$\mathbf{K}_s \mathbf{L}'_{sr} \left(\mathbf{K}_r\right)^{-1} = \mathbf{K}_r \left(\mathbf{L}'_{sr}\right)^T \left(\mathbf{K}_s\right)^{-1} = \begin{bmatrix} M & 0 & 0 \\ 0 & M & 0 \\ 0 & 0 & M \end{bmatrix}$$

- Voltage equations in expanded form:

$$V_{qs} = r_s i_{qs} + \omega\lambda_{ds} + p\lambda_{qs} \qquad V'_{qr} = r'_r i'_{qr} + \left(\omega - \omega_r\right)\lambda'_{dr} + p\lambda'_{qr}$$

$$V_{ds} = r_s i_{ds} - \omega\lambda_{qs} + p\lambda_{ds}, \qquad V'_{dr} = r'_r i'_{dr} - \left(\omega - \omega_r\right)\lambda'_{qr} + p\lambda'_{dr}$$

$$V_{0s} = r_s i_{0s} + p\lambda_{0s} \qquad V'_{0r} = r'_r i'_{0r} + p\lambda'_{0r}$$

- Flux linkage equations are

$$\lambda_{qs} = L_{ls} i_{qs} + M\left(i_{qs} + i'_{qr}\right) \qquad \lambda'_{qr} = L'_{lr} i'_{qr} + M\left(i_{qs} + i'_{qr}\right)$$

$$\lambda_{ds} = L_{ls} i_{ds} + M\left(i_{ds} + i'_{dr}\right) \qquad \lambda'_{dr} = L'_{lr} i'_{dr} + M\left(i_{ds} + i'_{dr}\right)$$

$$\lambda_{0s} = L_{ls} i_{0s} \qquad \lambda'_{0r} = L'_{lr} i'_{0r}$$

Voltage Equations in Arbitrary Reference Frame Variables

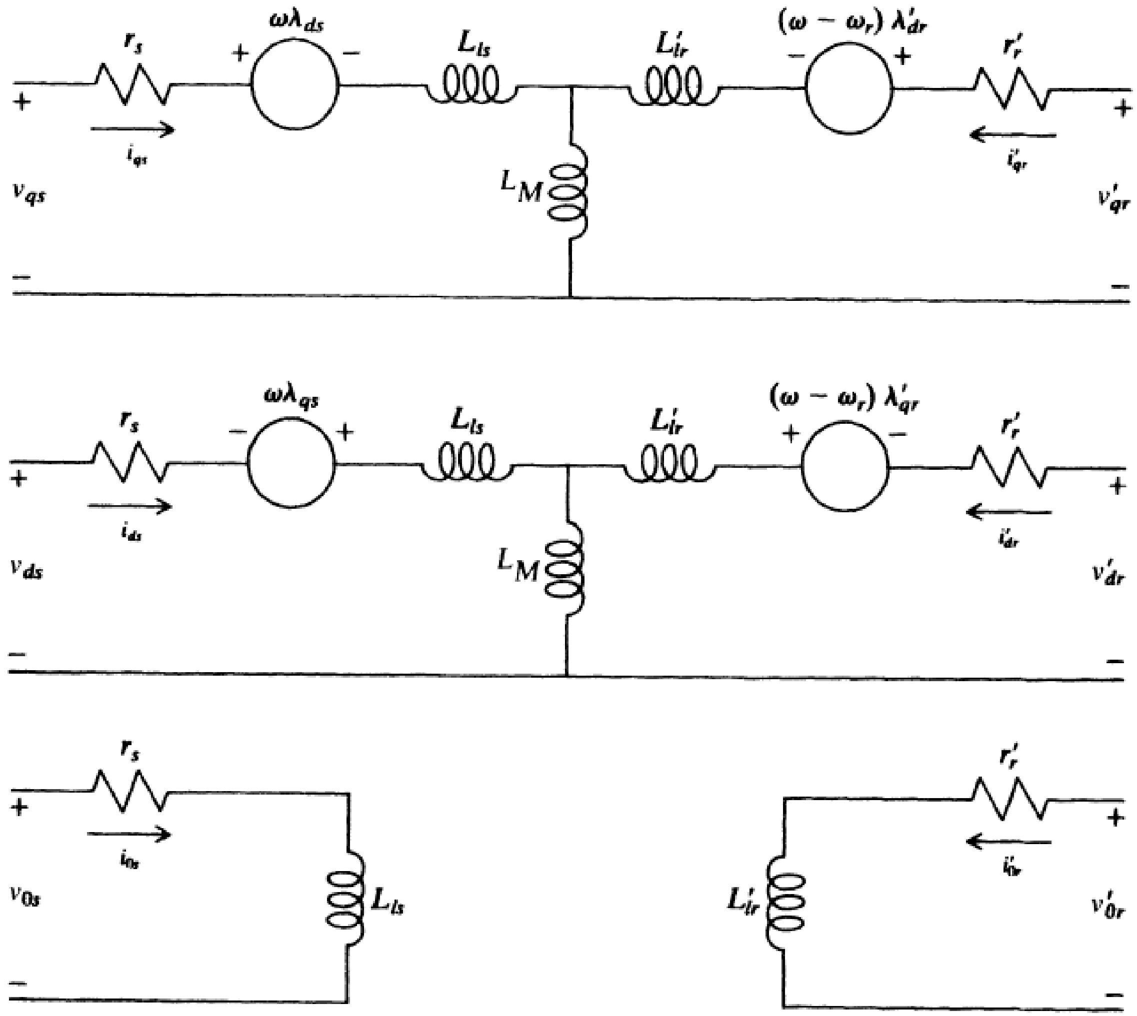


Figure 4.5-1 Arbitrary reference-frame equivalent circuits for a 3-phase, symmetrical induction machine.

Voltage Equations in Arbitrary Reference Frame Variables

- Since machine and power system parameters are nearly always given in ohms or percent or per unit of a base impedance, it is convenient to express the voltage and flux linkage equations in terms of reactances rather than inductances. Let:

$$\varphi = \lambda \omega_b$$

- Then

$$V_{qs} = r_s i_{qs} + \frac{\omega}{\omega_b}\varphi_{ds} + p\varphi_{qs}$$

$$V_{ds} = r_s i_{ds} - \frac{\omega}{\omega_b}\varphi_{qs} + \frac{p}{\omega_b}\varphi_{ds},$$

$$V_{0s} = r_s i_{0s} + \frac{p}{\omega_b}\varphi_{0s}$$

$$V'_{qr} = r'_r i'_{qr} + \frac{(\omega - \omega_r)}{\omega_b}\varphi'_{dr} + \frac{p}{\omega_b}\varphi'_{qr}$$

$$V'_{dr} = r'_r i'_{dr} - \frac{(\omega - \omega_r)}{\omega_b}\varphi'_{qr} + \frac{p}{\omega_b}\varphi'_{dr}$$

$$V'_{0r} = r'_r i'_{0r} + \frac{p}{\omega_b}\varphi'_{0r}$$

Voltage Equations in Arbitrary Reference Frame Variables

- Where flux linkages become flux linkages per second with the units of volts.

$$\varphi_{qs} = X_{ls} i_{qs} + X_m \left(i_{qs} + i'_{qr} \right) \qquad \varphi'_{qr} = X'_{lr} i'_{qr} + X_m \left(i_{qs} + i'_{qr} \right)$$

$$\varphi_{ds} = X_{ls} i_{ds} + X_m \left(i_{ds} + i'_{dr} \right), \qquad \varphi'_{dr} = X'_{lr} i'_{dr} + X_m \left(i_{ds} + i'_{dr} \right)$$

$$\varphi_{0s} = X_{ls} i_{0s} \qquad \varphi'_{0r} = X'_{lr} i'_{0r}$$

$$
\begin{bmatrix} v_{qs} \\ v_{ds} \\ v_{0s} \\ v'_{qr} \\ v'_{dr} \\ v'_{0r} \end{bmatrix} =
\begin{bmatrix}
r_s + \frac{p}{\omega_b} X_{ss} & \frac{\omega}{\omega_b} X_{ss} & 0 & \frac{p}{\omega_b} X_M & \frac{\omega}{\omega_b} X_M & 0 \\
-\frac{\omega}{\omega_b} X_{ss} & r_s + \frac{p}{\omega_b} X_{ss} & 0 & -\frac{\omega}{\omega_b} X_M & \frac{p}{\omega_b} X_M & 0 \\
0 & 0 & r_s + \frac{p}{\omega_b} X_{ls} & 0 & 0 & 0 \\
\frac{p}{\omega_b} X_M & \left(\frac{\omega-\omega_r}{\omega_b}\right) X_M & 0 & r'_r + \frac{p}{\omega_b} X'_{rr} & \left(\frac{\omega-\omega_r}{\omega_b}\right) X'_{rr} & 0 \\
-\left(\frac{\omega-\omega_r}{\omega_b}\right) X_M & \frac{p}{\omega_b} X_M & 0 & -\left(\frac{\omega-\omega_r}{\omega_b}\right) X'_{rr} & r'_r + \frac{p}{\omega_b} X'_{rr} & 0 \\
0 & 0 & 0 & 0 & 0 & r'_r + \frac{p}{\omega_b} X'_{lr}
\end{bmatrix}
\begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{0s} \\ i'_{qr} \\ i'_{dr} \\ i'_{0r} \end{bmatrix}
$$

$$
X_{ss} = X_{ls} + X_M
$$

$$
X'_{rr} = X'_{lr} + X_M
$$

$$
\begin{bmatrix} \psi_{qs} \\ \psi_{ds} \\ \psi_{0s} \\ \psi'_{qr} \\ \psi'_{dr} \\ \psi'_{0r} \end{bmatrix} =
\begin{bmatrix}
X_{ss} & 0 & 0 & X_M & 0 & 0 \\
0 & X_{ss} & 0 & 0 & X_M & 0 \\
0 & 0 & X_{ls} & 0 & 0 & 0 \\
X_M & 0 & 0 & X'_{rr} & 0 & 0 \\
0 & X_M & 0 & 0 & X'_{rr} & 0 \\
0 & 0 & 0 & 0 & 0 & X'_{lr}
\end{bmatrix}
\begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{0s} \\ i'_{qr} \\ i'_{dr} \\ i'_{0r} \end{bmatrix}
$$

$$\begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{0s} \\ i'_{qr} \\ i'_{dr} \\ i'_{0r} \end{bmatrix} = \frac{1}{D} \begin{bmatrix} X'_{rr} & 0 & 0 & -X_M & 0 & 0 \\ 0 & X'_{rr} & 0 & 0 & -X_M & 0 \\ 0 & 0 & \frac{D}{X_{ls}} & 0 & 0 & 0 \\ -X_M & 0 & 0 & X_{ss} & 0 & 0 \\ 0 & -X_M & 0 & 0 & X_{ss} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{D}{X'_{lr}} \end{bmatrix} \begin{bmatrix} \psi_{qs} \\ \psi_{ds} \\ \psi_{0s} \\ \psi'_{qr} \\ \psi'_{dr} \\ \psi'_{0r} \end{bmatrix}$$

where

$$D = X_{ss}X'_{rr} - X_M^2$$

Torque Equation in Arbitrary Reference Frame Variables

- Electromagnetic torque in terms of arbitrary reference frame variables may be obtained by substituting the equations of transformation in

$$T_e = \frac{P}{2}(i_{abcs})^T \frac{\partial}{\partial \theta_r}(L'_{sr})i'_{abcr}$$

$$= \frac{P}{2}\left[(\mathbf{K}_s)^{-1} i_{qd0s}\right]^T \frac{\partial}{\partial \theta_r}(L'_{sr})(\mathbf{K}_r)^{-1} i'_{qd0r}$$

- After some work, we will have the following:

$$T_e = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right) M (i_{qs} i'_{dr} - i_{ds} i'_{qr})$$

Torque Equation in Arbitrary Reference Frame Variables

- Where, T_e is positive for motor action. Other expressions for the electromagnetic torque of an induction machine are

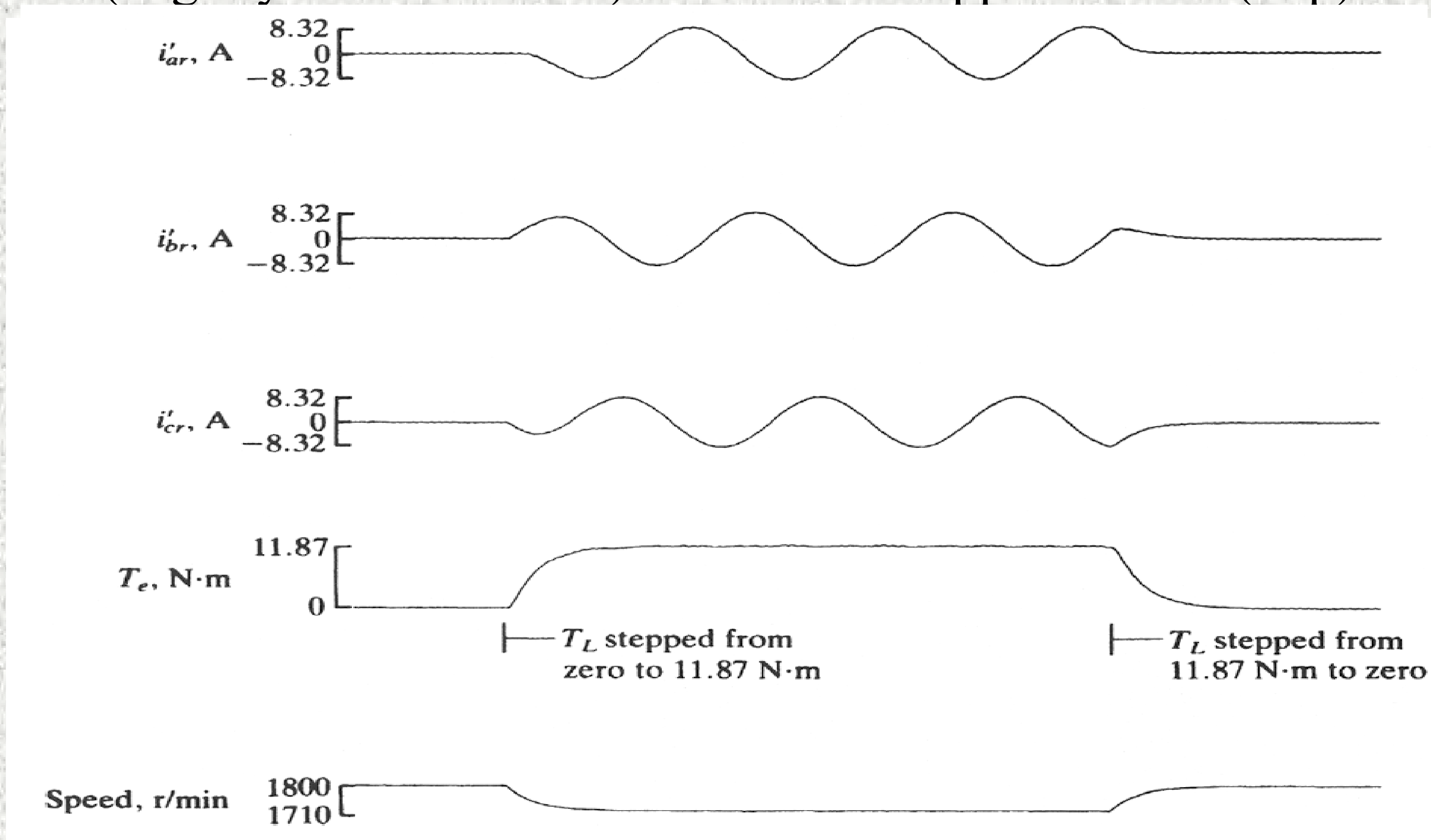
$$T_e = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)(\lambda'_{qr} i'_{dr} - \lambda'_{dr} i'_{qr})$$

$$T_{em} = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)(\lambda_{ds} i_{qs} - \lambda_{qs} i_{ds})$$

$$T_e = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)\left(\frac{1}{\omega_b}\right)(\varphi'_{qr} i'_{dr} - \varphi'_{dr} i'_{qr})$$

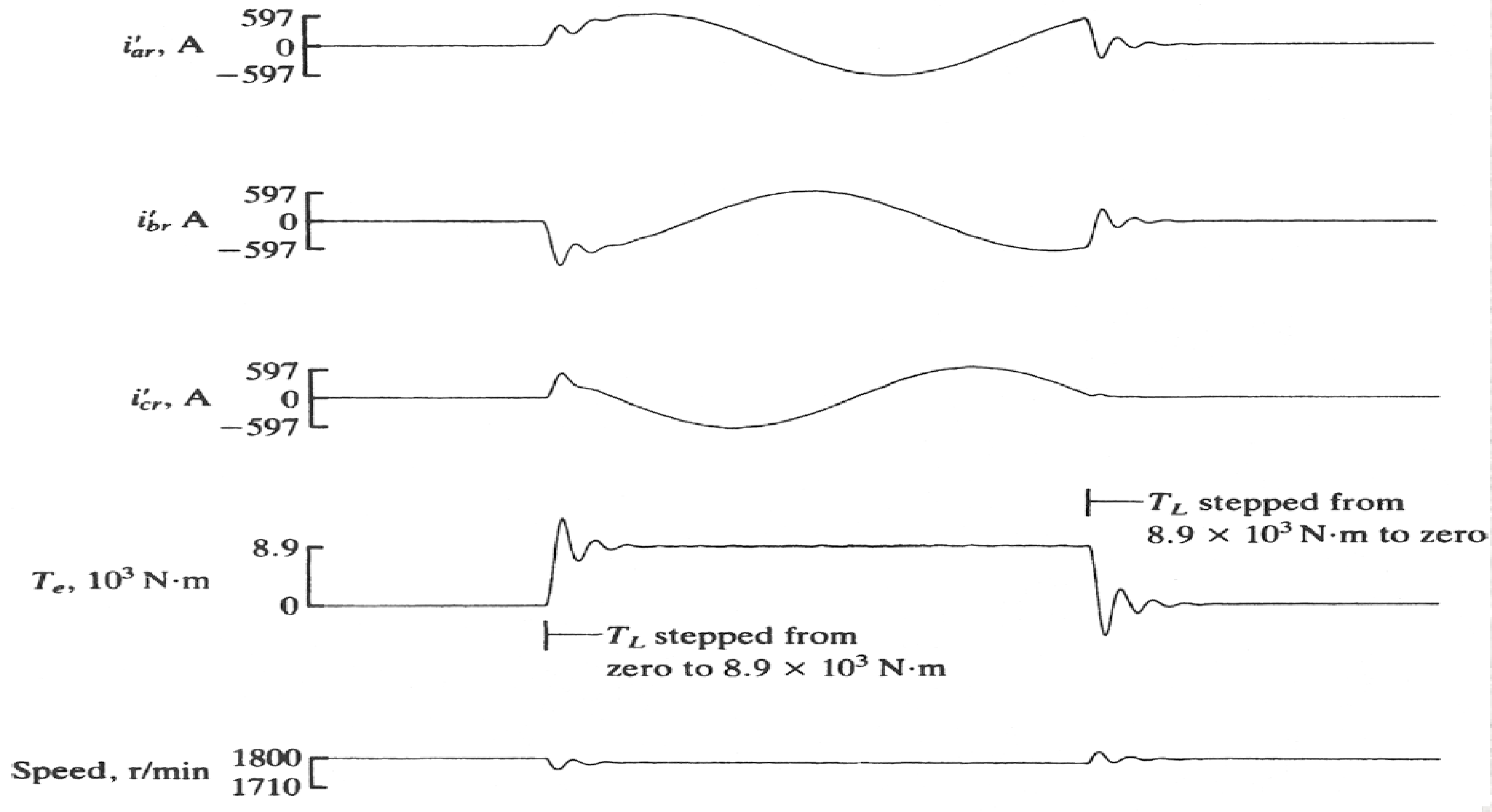
DYNAMIC PERFORMANCE DURING SUDDEN CHANGES IN LOAD TORQUE

- The load torque is first stepped from zero to base torque (slightly less than rated) and then is stepped to zero (3hp)



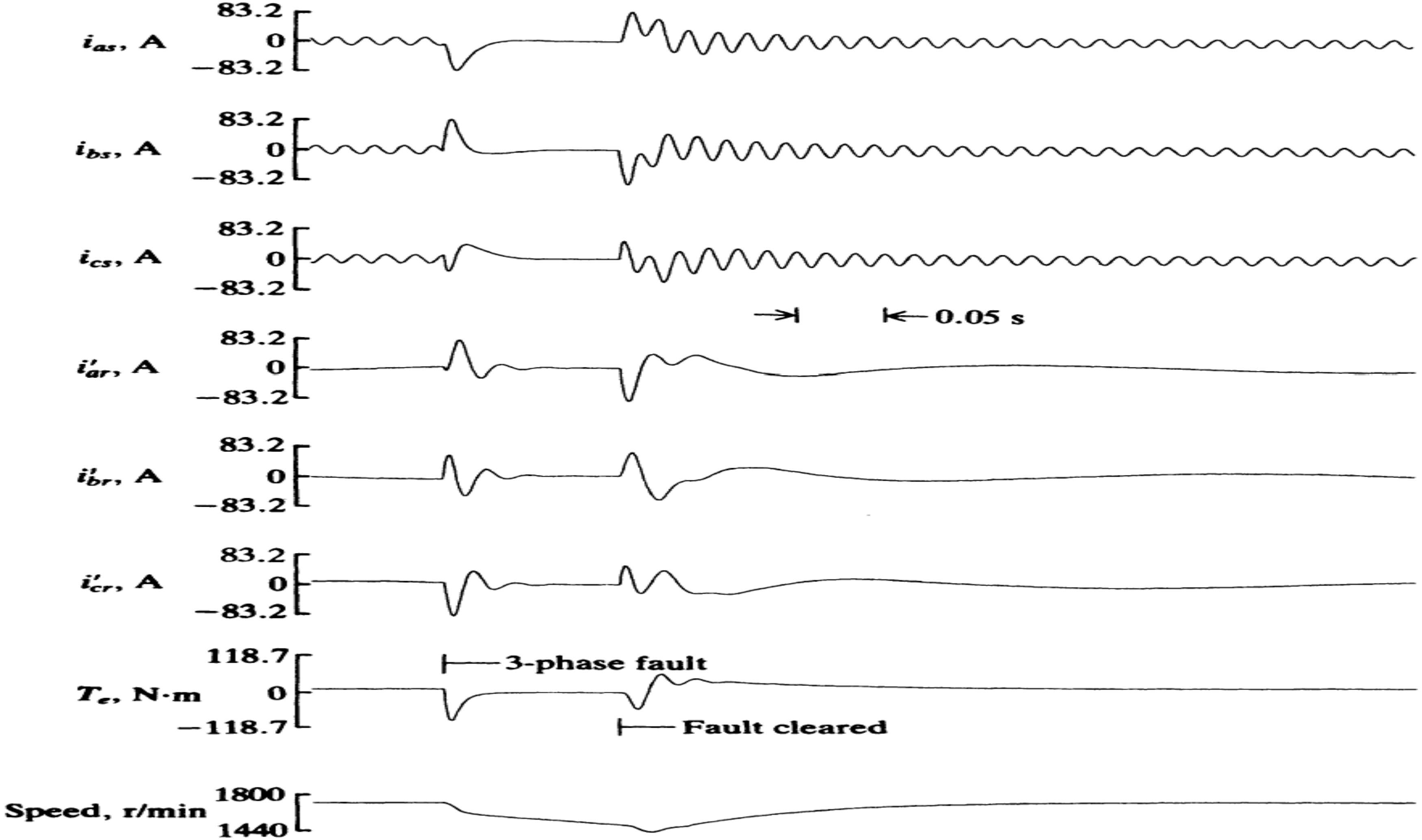
DYNAMIC PERFORMANCE DURING SUDDEN CHANGES IN LOAD TORQUE

- The load torque is first stepped from zero to base torque (slightly less than rated) and then is stepped to zero (2250hp)

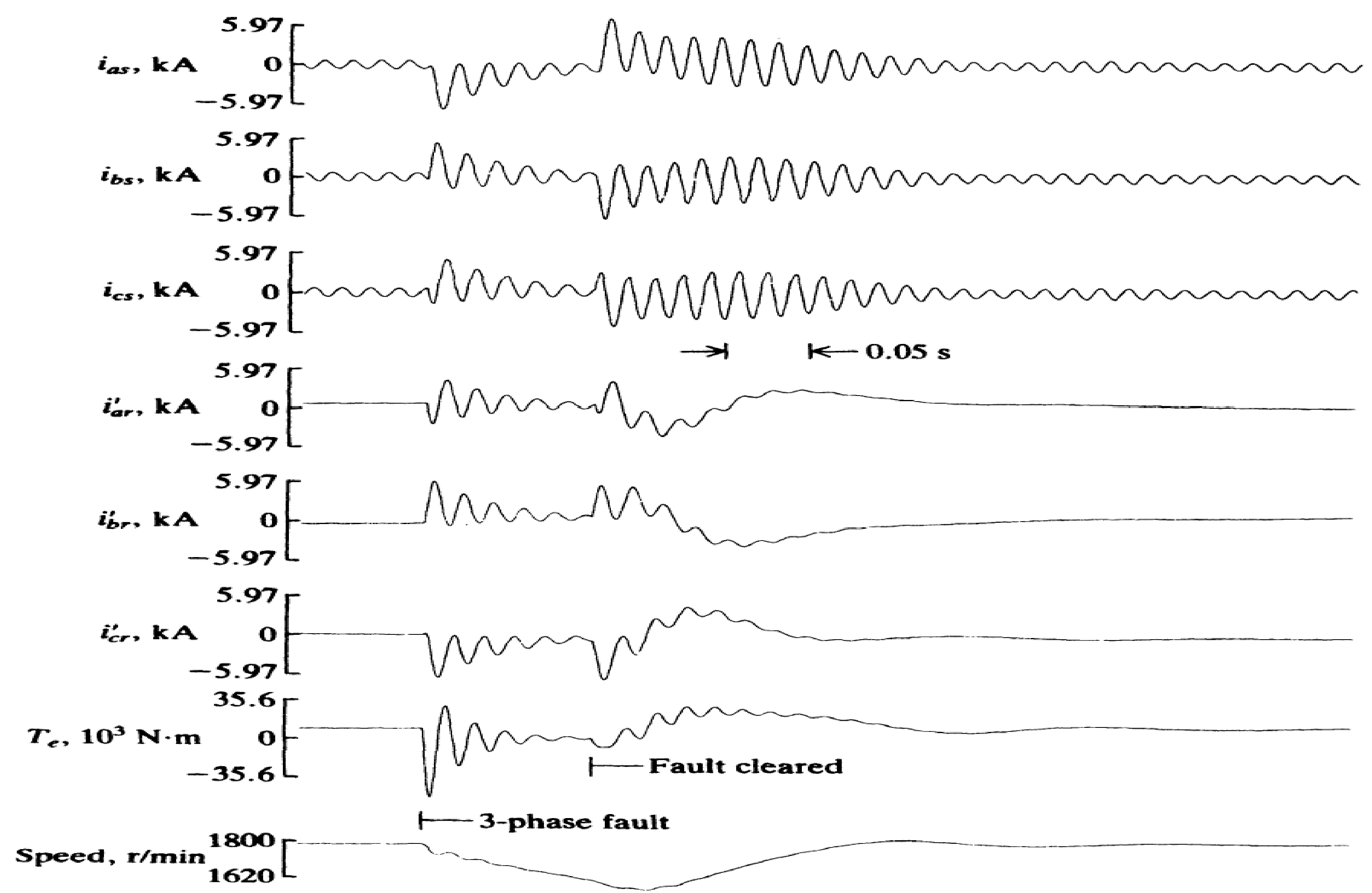


DYNAMIC PERFORMANCE DURING A 3-PHASE FAULT AT THE MACHINE TERMINALS

Dynamic performance of a 3-hp induction motor during a 3-phase fault

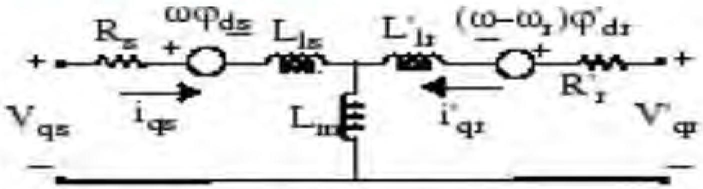


DYNAMIC PERFORMANCE DURING A 3-PHASE FAULT AT THE MACHINE TERMINALS

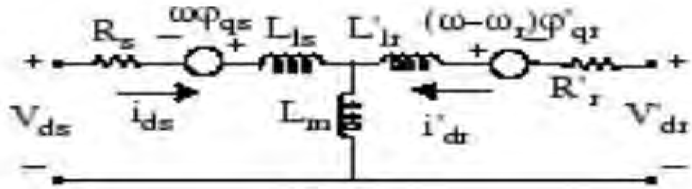


COMPUTER SIMULATION IN THE ARBITRARY REFERENCE FRAME

Electrical System



q axis



d axis

$$V_{qs} = R_s i_{qs} + \frac{d}{dt}\varphi_{qs} + \omega\varphi_{ds}$$

$$V_{ds} = R_s i_{ds} + \frac{d}{dt}\varphi_{ds} - \omega\varphi_{qs}$$

$$V'_{qr} = R'_r i'_{qr} + \frac{d}{dt}\varphi'_{qr} + (\omega-\omega_r)\varphi'_{dr}$$

$$V'_{dr} = R'_r i'_{dr} + \frac{d}{dt}\varphi'_{dr} - (\omega-\omega_r)\varphi'_{qr}$$

$$T_e = 1.5\,p(\varphi_{ds} i_{qs} - \varphi_{qs} i_{ds})$$

where

$$\varphi_{qs} = L_s i_{qs} + L_m i'_{qr}$$

$$\varphi_{ds} = L_s i_{ds} + L_m i'_{dr}$$

$$\varphi'_{qr} = L'_r i'_{qr} + L_m i_{qs}$$

$$\varphi'_{dr} = L'_r i'_{dr} + L_m i_{ds}$$

$$L_s = L_{ls} + L_m$$

$$L'_r = L'_{lr} + L_m$$

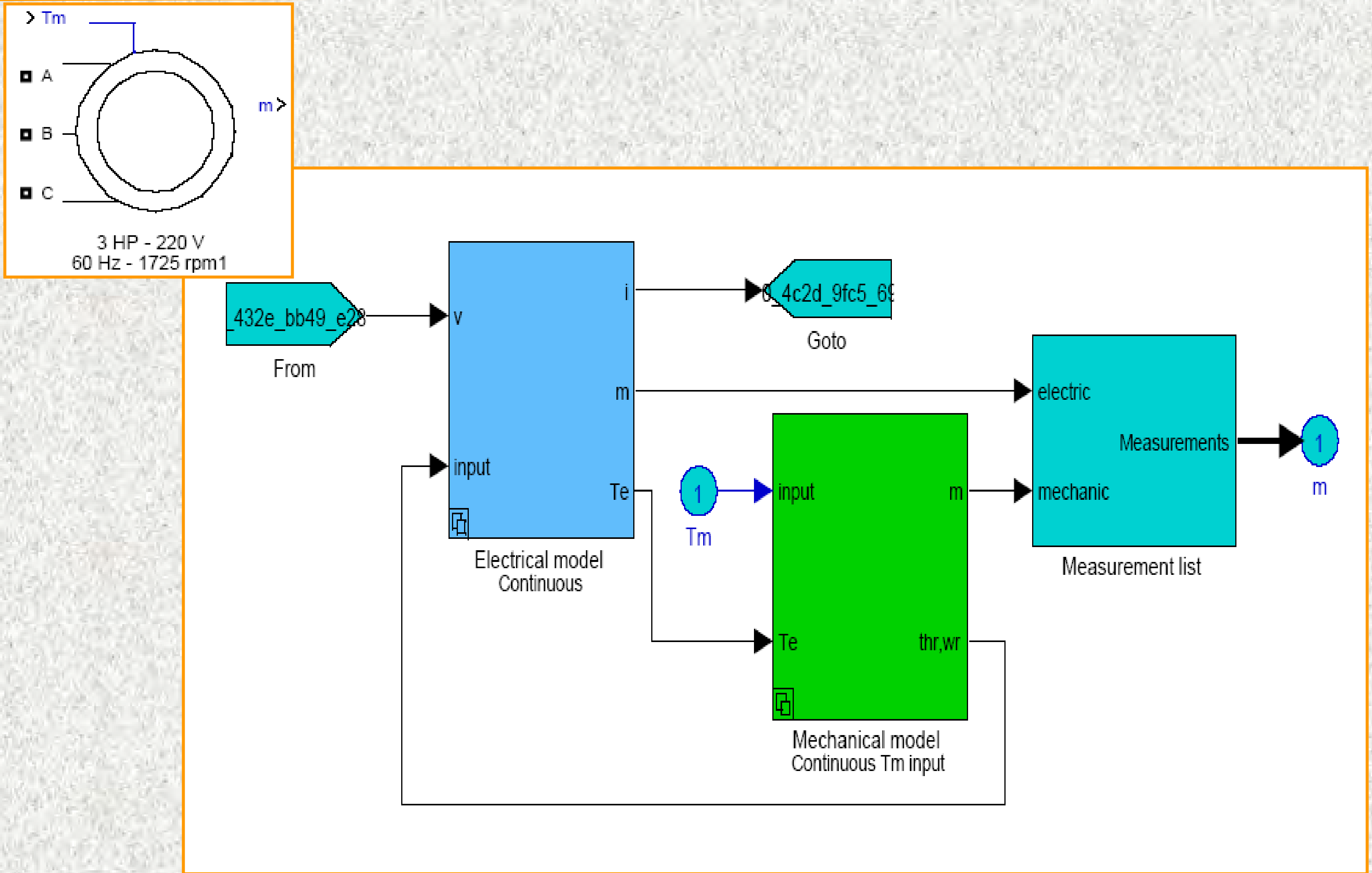
Mechanical System

$$\frac{d}{dt}\omega_m = \frac{1}{2H}(T_e - F\omega_m - T_m)$$

$$\frac{d}{dt}\theta_m = \omega_m$$

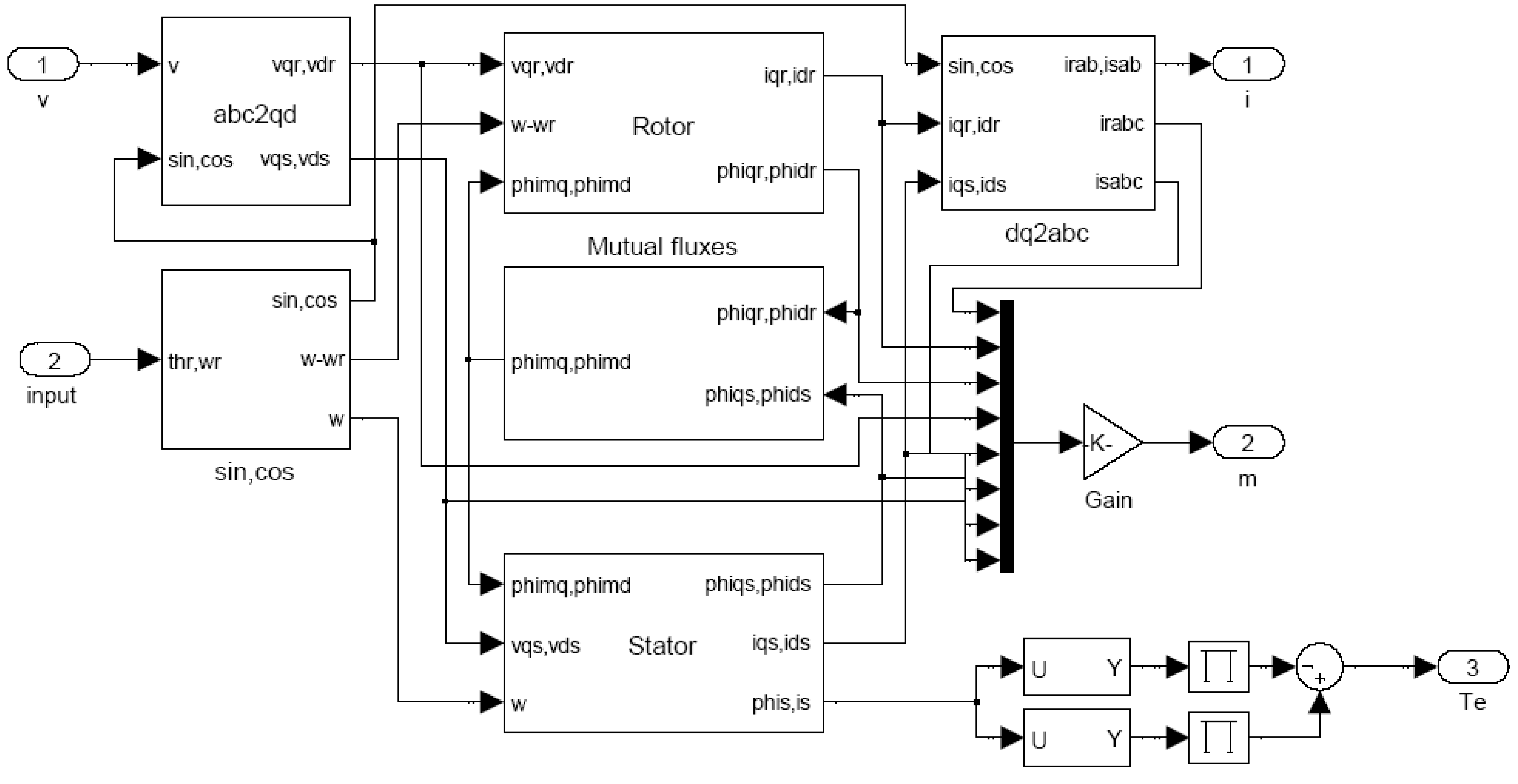
استاد درس: دکتر عباس کتابی

COMPUTER SIMULATION IN THE ARBITRARY REFERENCE FRAME

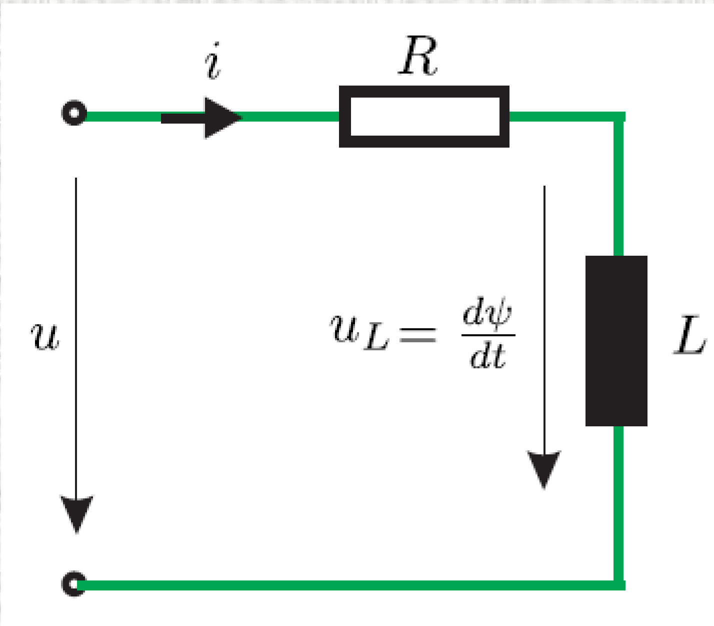


استاد درس: دکتر عباس کتابی

Electrical model



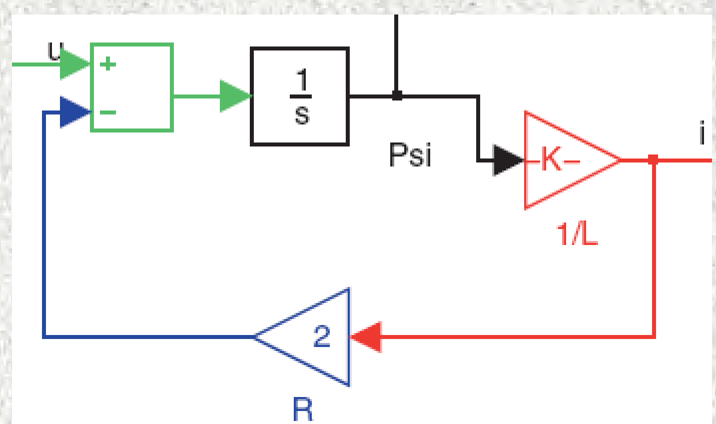
RL Circuit Simulink model



$$u = iR + \frac{d\psi}{dt}$$

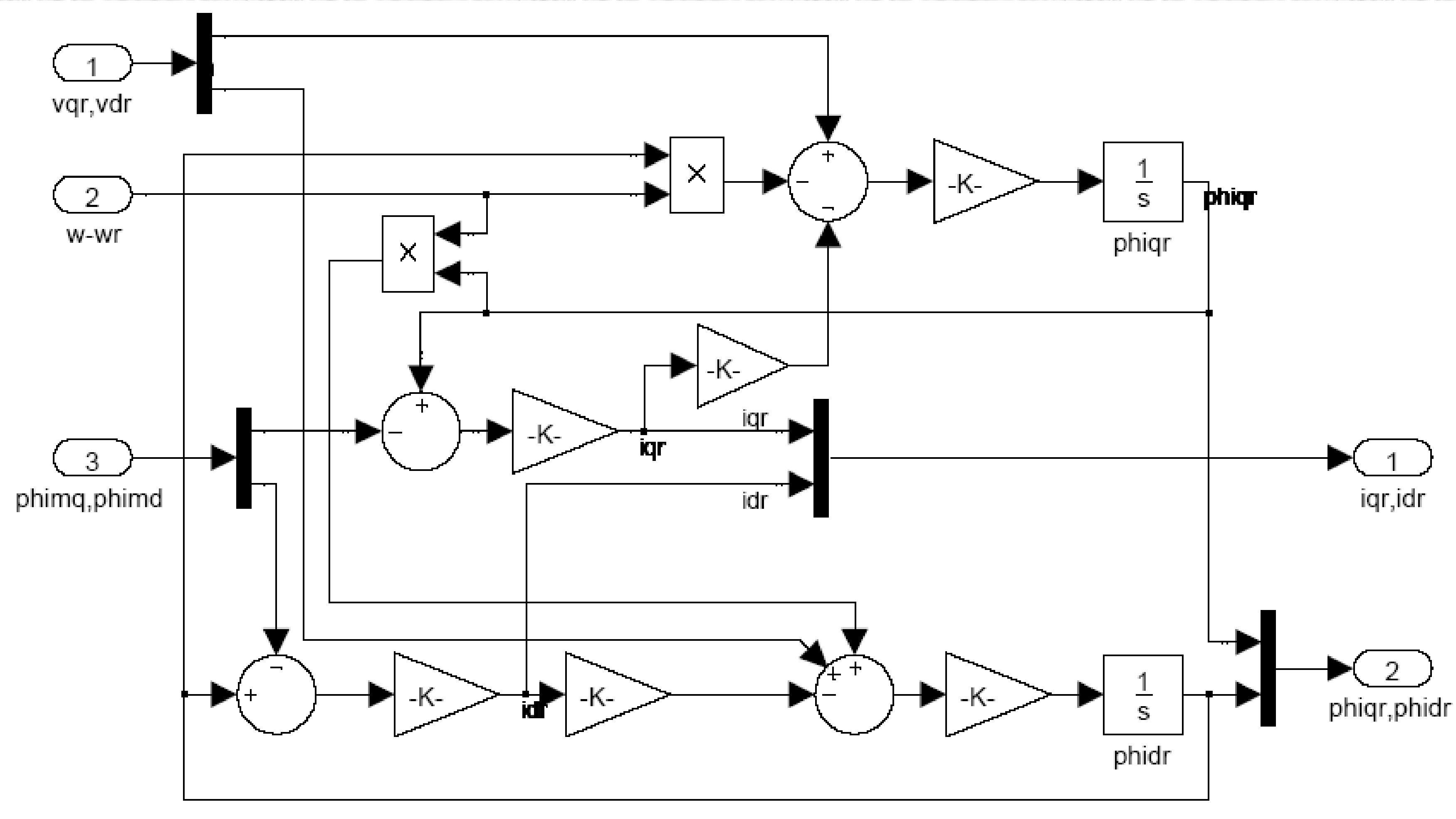
$$\psi = Li$$

$$u = \frac{R}{L}\psi + \frac{d\psi}{dt}$$



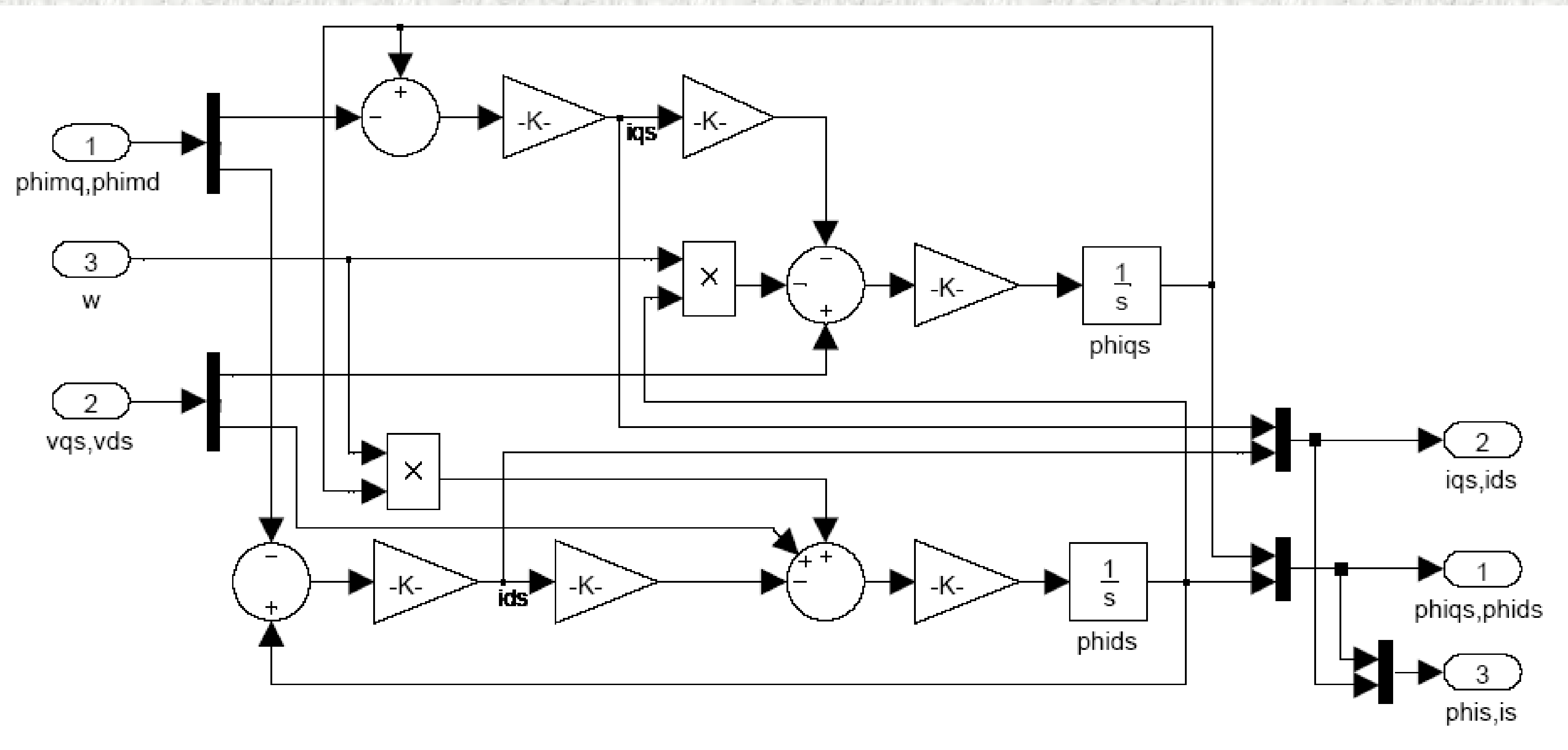
COMPUTER SIMULATION IN THE ARBITRARY REFERENCE FRAME

Rotor model



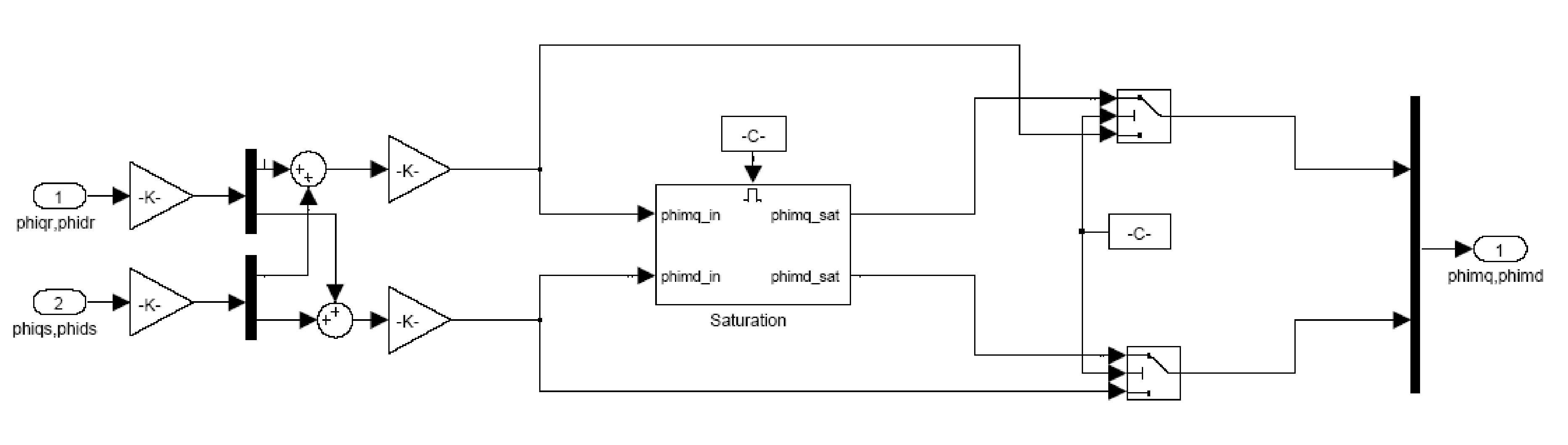
استاد درس: دکتر عباس کتابی

Stator model



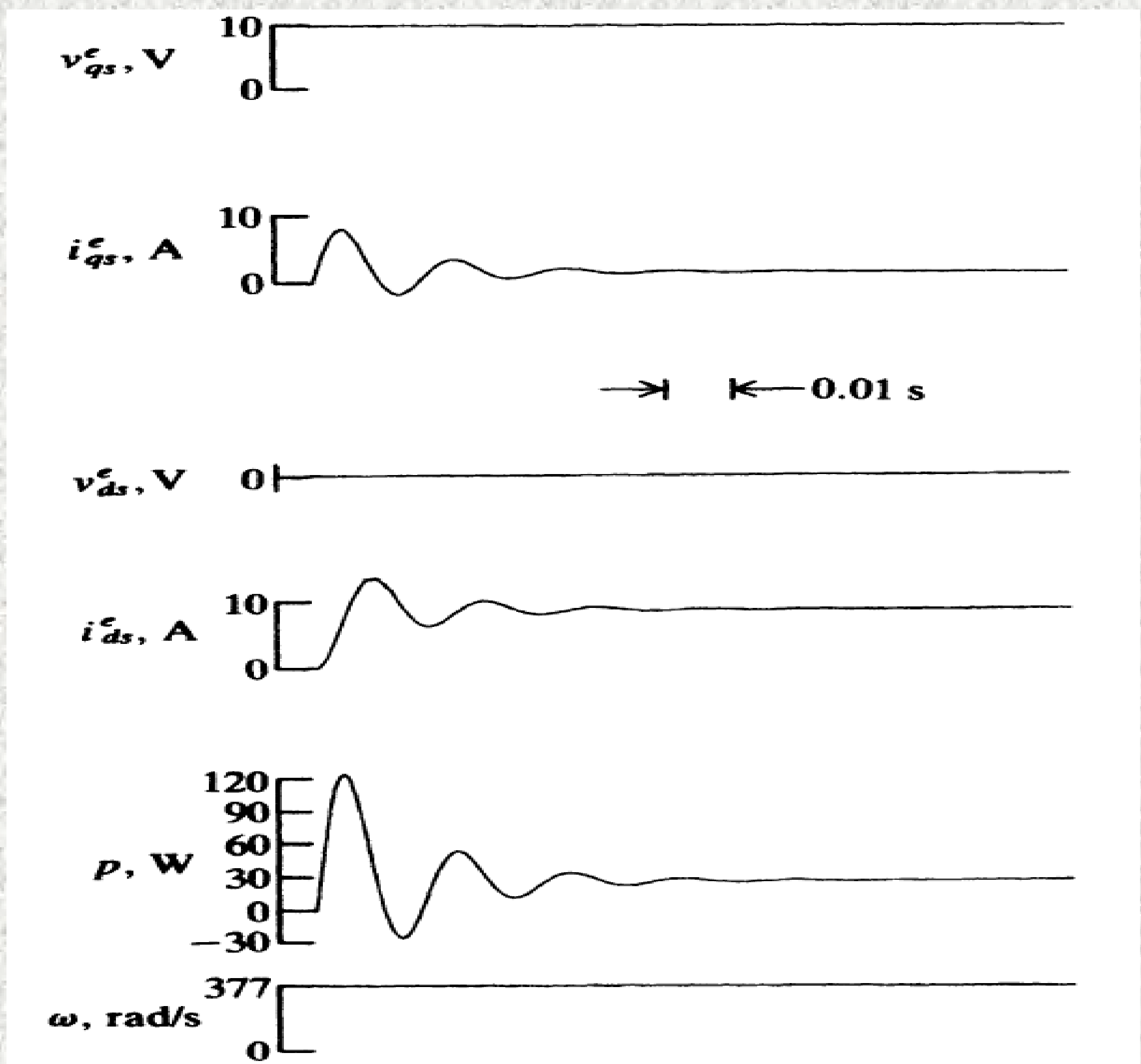
استاد درس: دکتر عباس کتابی

Mutual Fluxes model



Variables Observed From Several Frames of Reference

- In Synchronous Reference Frame



Variables Observed From Several Frames of Reference

- In Strange Reference Frame

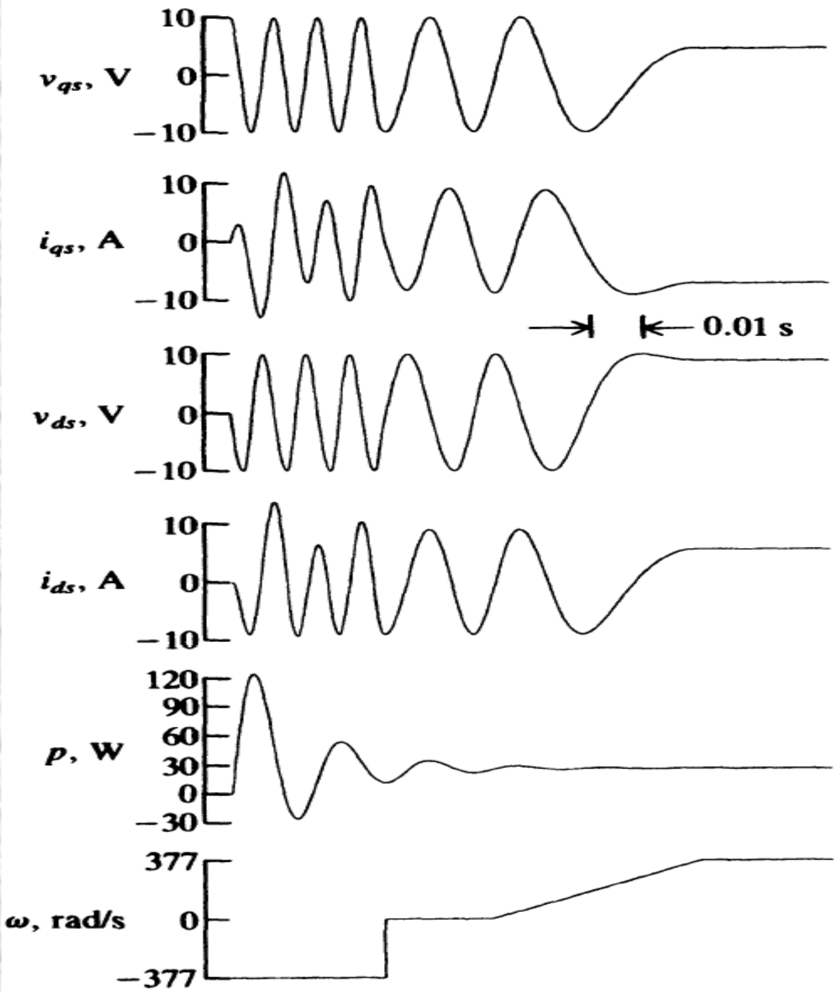


Figure 3.10-3 Variables of a stationary 3-phase system. First with $\omega = -\omega_e$, then ω is stepped to zero followed by a ramp change in reference frame speed to $\omega = \omega_e$.